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NOTES ON THE DESIGN OF SUPERCHARGED AND OVER-DIMENSIONED AIRCRAFT ENGINES.

by

Schwager

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by

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The purely supercharged motor must be considered as overloaded, because the increase of power with altitude reached by supercharging is limited, as the following example shows.

A certain motor gives for a normal compression ratio $\varepsilon_n = 5$ the mean pressure $(p_e)_n = 7.5$ atmospheres; the highest compression ratio allowed by the structural resistance is $\varepsilon_u = 7$, the mean pressure will increase in proportion to the improvement of the thermal efficiency η_t. For $k = 1.35$, we will have

$$\text{for } \varepsilon_n = 5, \ (\eta_t)_n = 0.431$$

$$\varepsilon_u = 7, \ (\eta_t)_u = 0.494$$

so that

$$(p_e)_u = \frac{(p_e)_n \cdot (\eta_t)_u}{(\eta_t)_n} = 8.6 \text{ at.}$$

When climbing, the power drops very nearly as the density when the carburetor is assumed perfectly adjusted. If at ground level the motor be throttled to $(p_e)_n = 7.5$ at. and this pressure maintained by progressive throttle opening, the mean effective pressure will fall starting from an air density ratio of $\frac{\gamma}{\gamma_0} = \frac{(p_e)_n}{(p_e)_u} = 0.872$, that is, nearly 1.3 km. altitude, for assumed standard air pressure and temperature. Up to this altitude, the assumption that the power drops proportionally with density, is not far from reality; even with defective carburetion the increase in gasoline consumption has no influence on the power, which can readily be seen from the fact that good motors do not drop their revolutions at this altitude.

By throttling, also, the temperature at the end of the compression will not be influenced, but the heat state of the cylinder will be so reduced that self-ignition will not take place. The adjustment must thus be made in the above-stated way.

On the other side, many flight tests with supercharged motors have shown that the carburetor would not be fully opened at the above calculated altitude, but had to be partially closed until two or three kilometers altitude was reached, so that the value of supercharging was decreased. The cause has been found to be that the carburetors on these motors were adjusted so economically that the mixture was too lean at the open throttle positions, so that the engines lost power or even stopped. On Fig. 1 these relations are represented, (power being expressed relatively, as proportion). From this Fig. 1 it is clear that only a small fraction of the theoretical gain by supercharging is realized for the above mentioned motors. When supercharged motors, which admit full throttle only from three kilometers altitude, give even better climb than ordinary motors, it is because of the fact that even the smallest increase in power has an influence on the climbing ability of the airplane.

The entire gain from supercharging appears only in connection with using a larger sized engine, because the oversized motor can and must be much more throttled down than the small sized supercharged motors.

A normal aircraft motor with a piston displacement volume equal to $(V_h)_n = 15\,l$ gives 175 H.P. at 1400 R.P.M., (n) with compression ratio $\varepsilon_n = 5$ and mean effective pressure $(p_e)_n = 7.5$ atmospheres. If from this motor we would like to develop an overdimensioned or oversized motor which can keep its power constant up to three kilometers altitude, we will be obliged, by the assumption that the drop of power is proportional to density, to make the piston displacement volume of this new motor inversely proportional to the density ratio at three kilometers altitude.

$$(V_h)_u = \frac{(V_h)_n}{\gamma_3/\gamma_0} = 20.6\,l.$$

Now for this increased piston displacement volume to get the same ground level power as for the normal motor, we must throttle down the mean pressure up to $(p_e)'_u = (p_e)_n \cdot \gamma_3/\gamma_0$ 5.45 at. If now this motor is supercharged up to $\varepsilon_u = 7$, its mean pressure is increased for full throttle in the ratio of the thermal efficiencies, that is again 8.6 at. At ground level and in climbing the mean pressure must be uniformly maintained at 5.45 at., by throttling. If we again assume that the mean pressure drops proportionally with density, then the engine power in this case can be kept constant up to 4.5 kilometers altitude. For the normal mean pressure $(p_e)_n = 5.45$ at. in this case, and with an original mean pressure of 8.6 at. the density ratio is

$$\frac{5.45}{8.6} = 0.634$$

The throttled down mean pressure is calculated from the normal pressure $(P_e)'_u = \frac{(P_e)_n \cdot \gamma_3/\gamma_0 (\eta_t)_5}{(\eta_t)_7} = (P_e)_n \cdot 0.634$

The power diagram of this supercharged and at the same time overdimensioned motor is given in Fig. 2. It has been assumed that the power drops exactly proportionally to density, because the carburetor up to three kilometers altitude still works normally. This is due to the fact that the density ratio is constantly kept equal to $\gamma_3/\gamma_0 = 0.727$ in front of the carburetor and in the carburetor float chamber above the gasoline. This is done by throttling at the carburetor entrance, and the gasoline consumption, up to six kilometers altitude, increases only very slightly. The mechanical efficiency is only slightly affected because the mechanical losses of the motor remain nearly the same when the motor is supercharged and overdimensioned.

If M_3 is the mixture ratio of gasoline to air at three kilometers altitude, for example, about 1 to 17, and M_6 the gasoline mixture ratio at six kilometers altitude, we then have

$$\frac{M_3}{M_6} = \sqrt{\frac{\gamma_6}{\gamma_3}} = 0.85 \qquad M_6 = \frac{M_3}{0.85} = \frac{1}{14.5}$$

As the theoretical mixture ratio is $\frac{1}{14.9}$ we thus have at six kilometers altitude only 2.5 per cent. insufficiency of air which does not cause any sensible drop of the thermal efficiency.

A simple scheme of throttling and adjustment for a supercharged and overdimensioned motor is represented on Fig. 3. The throttle a is the ordinary pilot's throttle, the throttles b and c are used for the altitude adjustment, the throttle b regulates the pressure of air supply to carburetor and the pressure above the gasoline in the float chamber, and the throttle c controls the altitude gas. The whole is so arranged that b is adjusted for ground level by aid of a stop and a spring, and c only put into action when the altitude is reached up to which the motor has to give constant power by the fact of overdimensioning. The throttle c controls the supercharging action. The throttles b and c are acted upon by a special handle or stick, and are for that purpose connected. The position of this stick or control handle will be adjusted by the hand according to the readings of the altimeter.

The calculation of the dimensions of an overdimensioned and supercharged motor is especially simple: Let us consider a 6-cylinder motor of 260 H.P. with a cylinder diameter of 100 mm. and stroke of 180 mm., 1400 R.P.M, which we wish to rebuild as a supercharged and overdimensioned motor that will have to keep its power constant up to three kilometers altitude. We will select as compression ratio, on the ground of empirical data $\mathcal{E}_u$ = 7 in comparison to $\mathcal{E}_n = 5$. The mean pressure of the normal motor $(P_e)_n = 7.65$ at. The throttled down mean effective pressure of the supercharged and overdimensioned motor is, for the overdimensioning alone, equal to

$$(P_e)'_u = (P_e)_n \cdot \gamma_3 / \gamma_0 = 5.55$$

and for the simultaneous supercharging

$$(P_e)'_u = \frac{(P_e)_n \cdot \gamma_x / \gamma_0 \cdot (\eta t)_5}{(\eta t)_7}$$

$$\gamma_x / \gamma_0 = \frac{(P_e)'_u \cdot (\eta_7)_7}{(P_e)_n \cdot (\eta_7)_5} = \frac{\gamma_3 / \gamma_0 \cdot (\eta_7)_7}{(\eta t)_5} = 0.832$$

where γ_x/γ_0 is the density ratio for the overdimensioned motor.

The piston displacement volume of this motor must thus be equal to

$$(V_h)_u = \frac{(V_h)_n}{0.832} \approx 26.1\ l$$

that is, increased about 20 per cent., compared with the normal motor.

The method of calculation indicated above is fully sufficient for practice. In relaity the gain in power by supercharging is a little greater, because the combustion speed is increased.

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Fig. 1

Fig 2

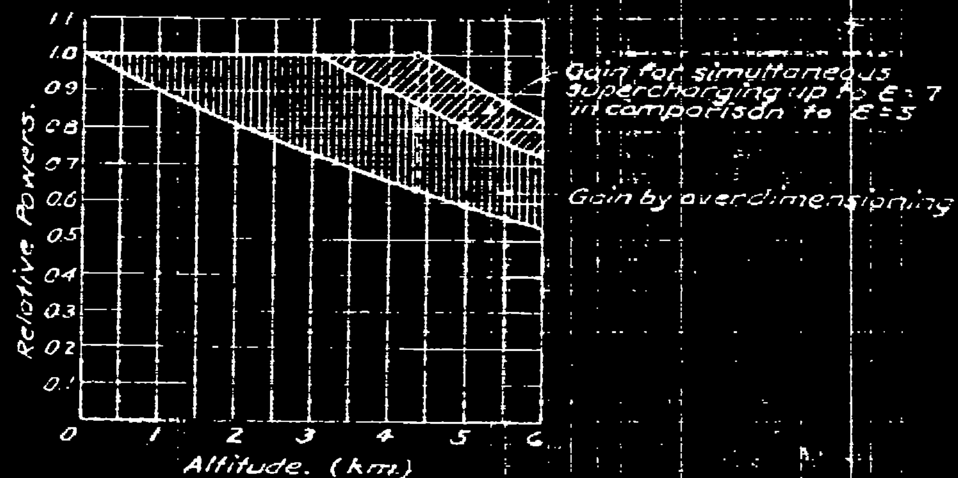

Fig. 3